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SENSITIVITY TO THE GRAVITINO MASS FROM SINGLE-PHOTON SPECTRUM AT TESLA LINEAR COLLIDER [a].

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The spectrum of single-photon events detected in the forward ($|cos\theta_\gamma| < 0.98$) and in the barrel region of a TESLA linear collider detector was studied in order to investigate the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$.

1 Introduction

A superlight gravitino $\tilde{\mathrm{G}}$ (several orders of magnitude lighter than the eV) is predicted by supersymmetric models [1]. In the last years, the possibility of detecting a light gravitino in accelerator experiments was studied in detail [2], the cross-section for the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$ was computed and experimental values were obtained by LEP experiments [3]. According to [2] this cross-section can be very large if the gravitino is sufficently light, independently of the masses of the other supersymmetric particles. Furthermore, in case all other supersymmetric particles are too heavy to be produced, the $e^+e^- \to \tilde{G}\tilde{G}\gamma$ could be the only signal of Supersymmetry at an e^+e^- collider.

The cross-section for the invisible reaction $e^+e^- \to \tilde{G}\tilde{G}$ is [2]:

$$\sigma_0 \equiv \sigma(e^+e^- \to \tilde{G}\tilde{G}) = \frac{s^3}{160\pi\,|F|^4}, \tag{1}$$

where F, defining the supersymmetry-breaking scale $\Lambda_S = |F|^{1/2}$, is related to the gravitino mass by $|F| = \sqrt{3}m_{3/2}M_P,\ M_P \equiv (8\pi G_N)^{-1/2} \simeq 2.4 \times 10^{18}$ GeV. The visible radiative production ($e^+e^- \to \tilde{G}\tilde{G}\gamma$) is given in terms of the double differential cross-section $d^2\sigma/(dx_\gamma, dcos\theta_\gamma)$ where x_γ and θ_γ are the fraction of the beam energy carried by the photon and the photon scattering angle with respect to the electron direction, respectively. For the dominant soft and collinear part of the photon spectrum ($x_\gamma \ll 1$, $sin\theta_\gamma \ll 1$) an estimate of the signal cross-section can be obtained by applying the standard approximate photon radiation formula to the lowest order $e^+e^- \to \tilde{G}\tilde{G}$ cross-section σ_0 at $s' = (1 - x_\gamma)s$:

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$$\frac{d^2\sigma}{dx_\gamma, dcos\theta_\gamma} \simeq \sigma_0[s'] \cdot \frac{\alpha}{\pi} \frac{1+(1-x_\gamma)^2}{x_\gamma sin^2\theta_\gamma}. \tag{2}$$

Since the total cross-section can be parametrised as:

$$\sigma = \frac{\alpha s^3}{320\pi^2|F|^4} \cdot I, \tag{3}$$

where $I \simeq \int_{x_\gamma^{min}}^{x_\gamma^{max}} dx_\gamma \int_{|cos\theta_\gamma^{min}|}^{|cos\theta_\gamma^{max}|} 4(1-x_\gamma)^3 \cdot \frac{1+(1-x_\gamma)^2}{x_\gamma sin^2\theta_\gamma} dcos\theta_\gamma$, it is evident that, in order to achieve the largest sensitivity for the signal, the measured spectrum should cover as much as possible the region of low energy and low polar angle photons. On the other hand, this region is also populated by the background from radiative $e^+e^- \to e^+e^-(\gamma)$ events where both leptons escape undetected along the beam pipe. In order to suppress such a background a cut on the photon transverse energy is necessary. In the TESLA environment, this cut should take into account the Luminometer capability to veto scattered electrons/positrons in presence of the machine background.

An irreducible physical background is due to single-photons from the process $e^+e^- \to \nu\bar{\nu}\gamma$ which have a polar angle distribution similar to the signal but in the energy spectrum they present the characteristic Z^0 return peak at $x_\gamma = 1 - \mathrm{M_Z}^2/\mathrm{s}$. As a consequence, an evidence of $e^+e^- \to \tilde{G}\tilde{G}\gamma$ will show-up as an excess of events over the $e^+e^- \to \nu\bar{\nu}\gamma$ background in the region far from the radiative Z^0 return. Since the signal cross-section (3) grows as the sixth power of the centre-of-mass energy, the signal sensitivity is dominated by the the highest energy data.

In case no signal is detected, a limit σ_l on the cross-section (3) would correspond to a lower limit on the gravitino mass[2]: $m_{3/2} > 3.8{\cdot}10^{-6}eV \left[\frac{\sqrt{s}(GeV)}{200}\right]^{3/2} \left[\frac{I}{\sigma_l}\right]^{1/4}$.

This note evaluates the sensitivity to this process for two possible high luminosity runs (500 fb^{-1}) at the TESLA Linear Collider at $\sqrt{s}$ = 500 and 800 GeV.

2 Apparatus and event selection

A basic description of a possible detector for TESLA can be found in[4].

The present sensitivity evaluation is based on the measurement of the electromagnetic energy clusters in the Forward and in the Barrel Electromagnetic Calorimeter, and in the Luminometer, as well as on the capability of vetoing the charged particles using the tracking devices. An event is selected as single-photon candidate if it satisfies the following criteria:

- one electromagnetic energy cluster with $E_\gamma > 10$ GeV, $x_\gamma < 0.7$ and $\theta_\gamma > 11°$;

- no energy released in the Luminometer above the machine background level;

- no charged tracks;

- the transverse momentum detected in the calorimeter incompatible with the presence of two beams both missing the Luminometer: $p_t > 0.025 \cdot (\sqrt{s} - E_\gamma)$ GeV.

The p_t cut together with the Luminometer veto is adopted in order to remove the background from radiative $e^+e^- \to e^+e^-(\gamma)$ events with both leptons undetected in the beam pipe. As it can be seen in table 1, the relevant detector for the acceptance is the Luminometer whose minimum angle defines the minimum transverse momentum required for the photon detected in the Forward or Barrel calorimeter. The minimum photon energy the calorimeters are able to detect is therefore not relevant for the signal sensitivity and then the analysis can be performed with very high efficiency with any kind of Electromagnetic Calorimeter. It is assumed that the Hadron Calorimeter and Scintillator informations can be used to get rid of cosmic ray background.

Table 1: The acceptance I for the radiative photon spectrum as function of several cut parameters for $\sqrt{s} = 800$ GeV. The dominant influence of the p_t cut is evident.

I	E_γ^{min}	θ_γ^{min}	$p_t/(\sqrt{s} - E_\gamma)$
8.23	10	11	0.038
10.63	10	11	0.030
12.70	10	11	0.025
12.70	6	11	0.025
12.68	20	11	0.025
12.44	10	13	0.025
12.13	10	15	0.025
15.46	10	11	0.020

3 Expected results

The detection efficiency expected with the selection criteria defined above depends on the detector details but it can be conservatively assumed to be similar to that of the LEP experiments (the ALEPH efficiency $\epsilon_\gamma = 77\%$ is used). Since the results depends on the efficiency with a power 1/4, this assumption does not influence significantly the final sensitivity.

The main background $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ cross-section has been computed with KORALZ [5] and NUNUGPV [6] programs at 500 and 800 GeV [b] and it is in the range $1.1 \div 1.5$ pb inside the acceptance region. The corresponding expected number of events with 500 fb^{-1} is then $550 \div 750{\times}10^3$ events and hence the relative statistical error would be in the range $1.1{\div}1.3 \times 10^{-3}$.

Given the high background rate, the systematic uncertitude on its measurement determines the sensitivity for the signal detection. Assuming the experimental systematics being dominated by the absolute Luminosity determination (a conservative value for $\Delta\mathcal{L}/\mathcal{L}$=1% was given in [4]) the sensitivity as function of the relative error $\Delta\sigma/\sigma$ on the $e^+e^- \rightarrow \nu\nu\gamma$ cross-section measurement is shown in Fig. 1 for a 95% Confidence Level limit and for a 5 standard deviations discovery. For a total error of about 0.5% the limit at 800 (500) GeV would be $m_{3/2} > 1.8\ (0.8) \times 10^{-4}$ eV at 95 % C.L.. This error value is compatible with the expectation for the future theoretical precision on the cross-section computation [7]. The analysis can be improved by comparing the measured energy spectrum with the background and signal+background expected ones by means of the Likelihood Ratio technique [8].

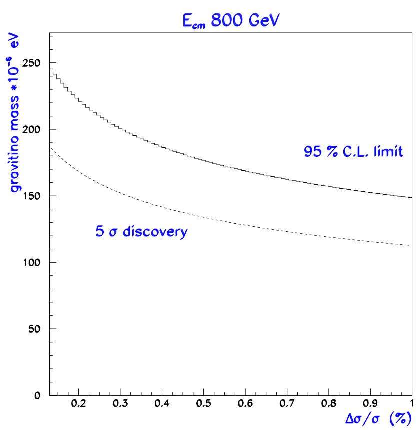

Figure 1: Sensitivity to $\tilde{\mathrm{G}}$ mass as function of the relative error on the $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ background cross-section at 800 GeV centre-of-mass Energy.

[b] The precision of both programs at the Linear Collider energies is of the order of 20%÷30%. The author wish to thank A. de Min for his help in the Monte-Carlo data production.

4 Conclusions

The channel $e^+e^- \to \gamma X_{invisible}$ is a very important tool for investigating new Physics. Excess of events in the low energy part of the photon spectrum for the highest e^+e^- energy could be due to superlight $\tilde{\mathrm{G}}$ production or, as recently claimed [9], to Extra Dimensions in Quantum Gravity. Unfortunately the presence of a very high backgrond from the $e^+e^- \to \nu\bar{\nu}\gamma$ channel requires to measure the single photon cross-section with a very high accuracy and to compute the expected cross-section with high precision in order not to spoil the sensitivity.

A preliminar evaluation of the sensitivity to the gravitino mass for a machine delivering about 500 fb^{-1} at $\sqrt{s} = 800$ GeV is $m_{3/2} \sim 1.5 \div 2.3 \times 10^{-4}$ eV corresponding to $\sqrt{|F|} \sim 0.8 \div 1$ TeV.

The same experimental analysis can be applied to the search for Quantum Gravity Extra Dimensions.

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